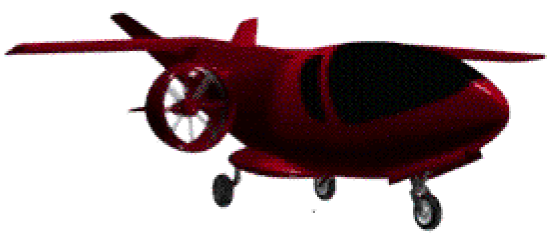
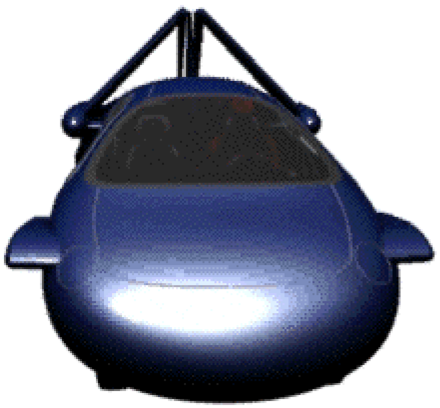
Personal Air Vehicle Exploration (PAVE)



VTOL CONCEPT



ROADABLE CONCEPT

Mark D. Moore
NASA Langley Research Center

PAVE Introduction

Current Solution: A fun, expensive hobby with some usefulness, but not nearly enough.

=

+

Future Solution: Door to door personal transportation, a blending of car and plane.

After being exposed to cars for 100 years, can we look into the future and understand the mission, concepts, and technologies for higher capacity and faster solutions?

PAVE Overview

Mission

Door to door personal travel (a system solution involving air and ground)

- **Live, shop, entertain, work... where you want, when you want**

Improvements in lifestyle and benefits for entire U.S. population

-More-

How is PAVE different from prior efforts?

Small companies have been trying to do this for 50 years

-More-

- **Minimal facilities, funding, expertise, technology development**

No prior system study performed

- **Design by constraint, requirement matrix, evaluation by metric**

-More-

How is PAVE revolutionary?

-More-

PAVE offers large initial, quantifiable benefits

- **Mobility, Capacity, Accessibility**

PAVE offers future benefits of a paradigm shift

- **Distributed network redundancy, Infrastructure investment, etc...**

Comparison to Enterprise Objectives

PAVE addresses many Aerospace Technology Enterprise objectives:

- Increased Mobility

  "enable people to travel faster and farther, anywhere, anytime"
- Increased Capacity - both at hub and spoke, and on highways
- Increase Safety, Reduce Emissions, Reduced Noise
- Pioneer Technology Innovation
- Commercialize Technology

PAVE meets additional NASA and Langley critical needs

- SATS is developing the air highways, PAVE is developing the air cars.
- NASA can invest where there is no near term ROI, with relatively low cost.
- NASA researchers believe we can make a difference…and are motivated.
- High visibility, high risk, high payoff

Study Objective and Approach

Establish a foundation

- Review prior concepts and current relevant technologies.
- Extract requirements, missions, and constraints
- Establish metrics as a basis for comparison.
- Define potential infrastructure scenarios.
- Develop baseline vehicles with current technology .

Explore the design space

- Define, establish, and integrate synergistic technologies (2015 TRL 6).
- Develop advanced concepts utilizing physics based methods.
- Compare concepts to reference baselines, each other, and alternate travel modes.

Determine technology investment approach

- Show technology sensitivities and gaps for the various mission concepts.
- Show assumption sensitivities to understand the elasticity of the design space.
- Present the study results in a highly interactive, intuitive and visual format.

PAVE Technologies (2015 TRL 6)

SATS Airspace Control, Avionics, and Manufacturing (2007) -More-

Propulsion

- Reciprocating engines -More-
- Turbofan and turboshaft engines -More-
- Distributed propulsion mini-engines systems -More-
- Dual mode air/ground power transmission system -More-
- Electric propulsion -More-
- Noise reduction (shielding, quiet fans, acoustic damping)

Aerodynamics

- Circulation Control -More-

Aero-Propulsive Systems and Controls

- Distributed inlet coupled to wing boundary layer control -More-
- Circulation Control Channel Wing -More-
- Multi-Gas Generator Fan / Circulation Control Nacelle -More-

Structures

- Highly constrained span wing systems -More-
- Ultra lightweight structures -More-
- Failsafe articulating structures with active sensors

PAVE Study Team

NASA

- LaRC Systems Analysis
- LaRC Configuration Aerodynamics Branch
- GRC Systems Analysis
- Ames Systems Analysis

Partners

- Boeing Long Beach
- Virginia Polytechnic Insititute
- Cal Poly San Luis Obispo
- Georgia Tech

Leveraging Programs

- AGATE, SATS, uSATS, GAP Programs
- LaRC Virtual Flap Circulation Control Morphing Workpackage
- LaRC Circulation Control Channel Wing C&I
- LaRC Distributed Propulsion Concept C&I
- DARPA Micro-engine Program

PAVE Concepts

Reference Conventional Baselines

- Auto, Taxi, Rental Car, Commercial Air
- CTOL, STOL, SSTOL (Modern certified conventional)
- SSTOL (Autogyro)
- VTOL (Helicopter)

Single Mode Advanced Concepts

- LaRC CTOL, STOL, SSTOL (Tailfan) -More-
- LaRC SSTOL (Dual Spiral Duct)
- LaRC VTOL (Tilt Nacelle) -More-
- GaTech SSTOL, VTOL

Dual Mode Advanced Concepts

- Cal Poly CTOL, STOL, SSTOL, VTOL (Turbofan)
- LaRC CTOL Highway (Mercedes Vaneo/Cirrus based turbofan) -More-
- VPI CTOL, STOL (Propeller) -More-
- LaRC SSTOL Side-street (Single Spiral Duct) -More-
- LaRC VTOL Side-street (Tilt Nacelle) -More-
- Boeing VTOL Army LAMV

PAVE Summary

Study

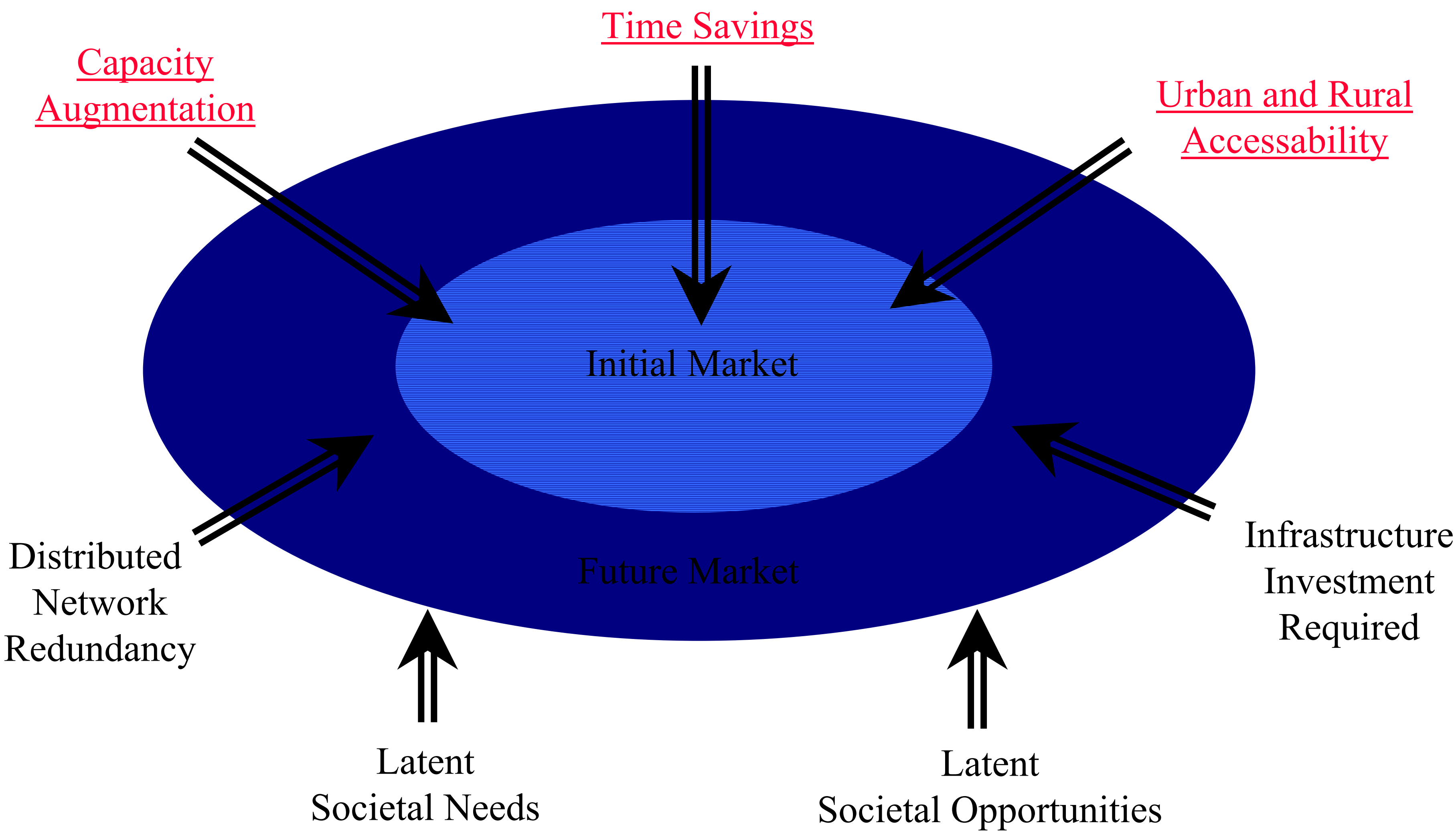
- A cross-disciplinary and cross-cultural team has been organized
- Several layers of infrastructure solutions considered (CTOL to VTOL) -More-
- Mission focus is on point to point travel, also some specialty missions
- Common ground rules
- Comparison based on relevant metrics (involving cost effectiveness)
- Highly integrated designs require detailed physics based tools
- Contractor and in-house results will be complete in December.

Findings

- Design constraints are defining the problem, not performance.
- Utilization is a primary concern (addition of air-taxi and air-rental).
- Poor performance of baselines, and availability of new synergistic technologies make this mission appear fertile for major improvements with advanced designs.
- Circulation control and distributed engine technologies are highly synergistic
- Contacts with GM and Ford, possibility of joint workshop next spring.
- Follow on work will provide detailed designs, technologies, and costing as well as greater depth in top level systems benefits.

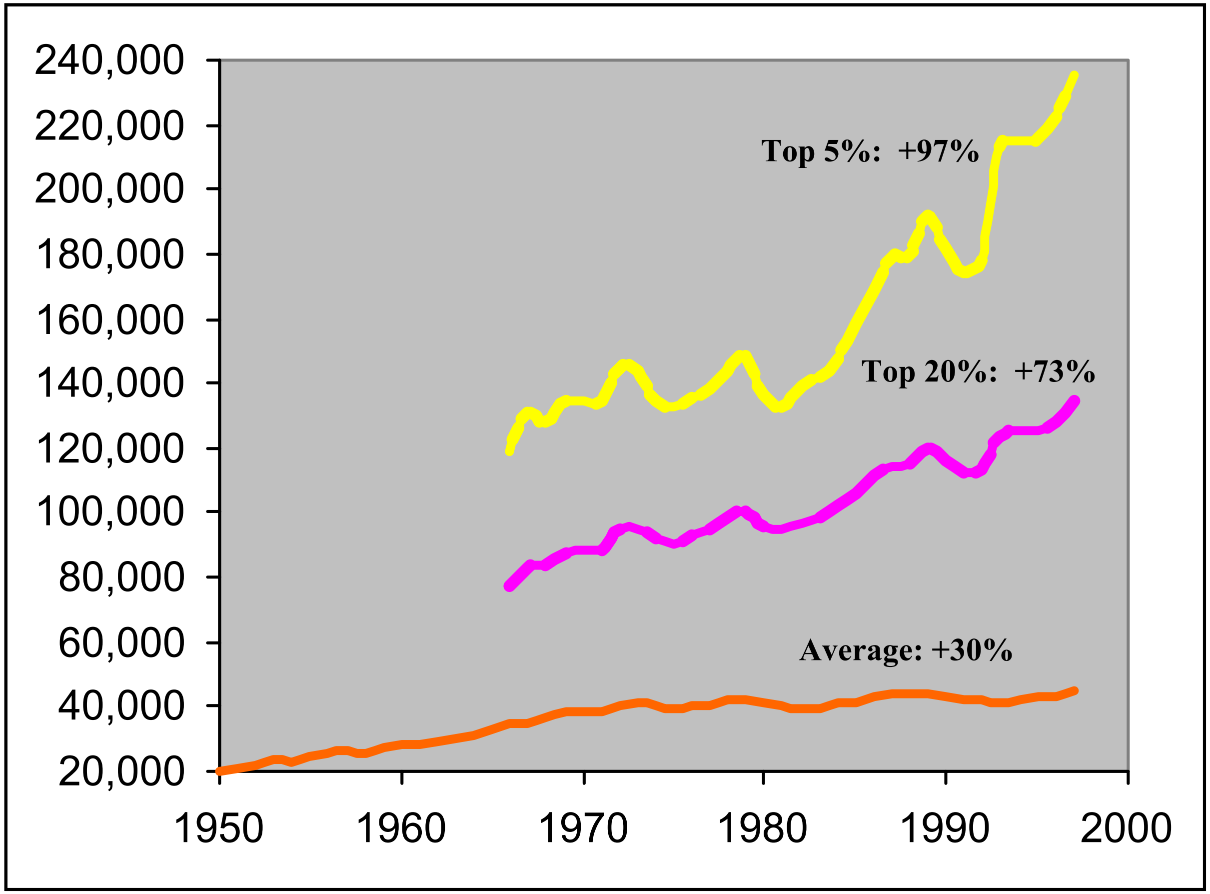
Backup Material

PAVE Benefits and Market



PAVE Time Benefit

"…Time is the scarce commodity of the 21st century..."

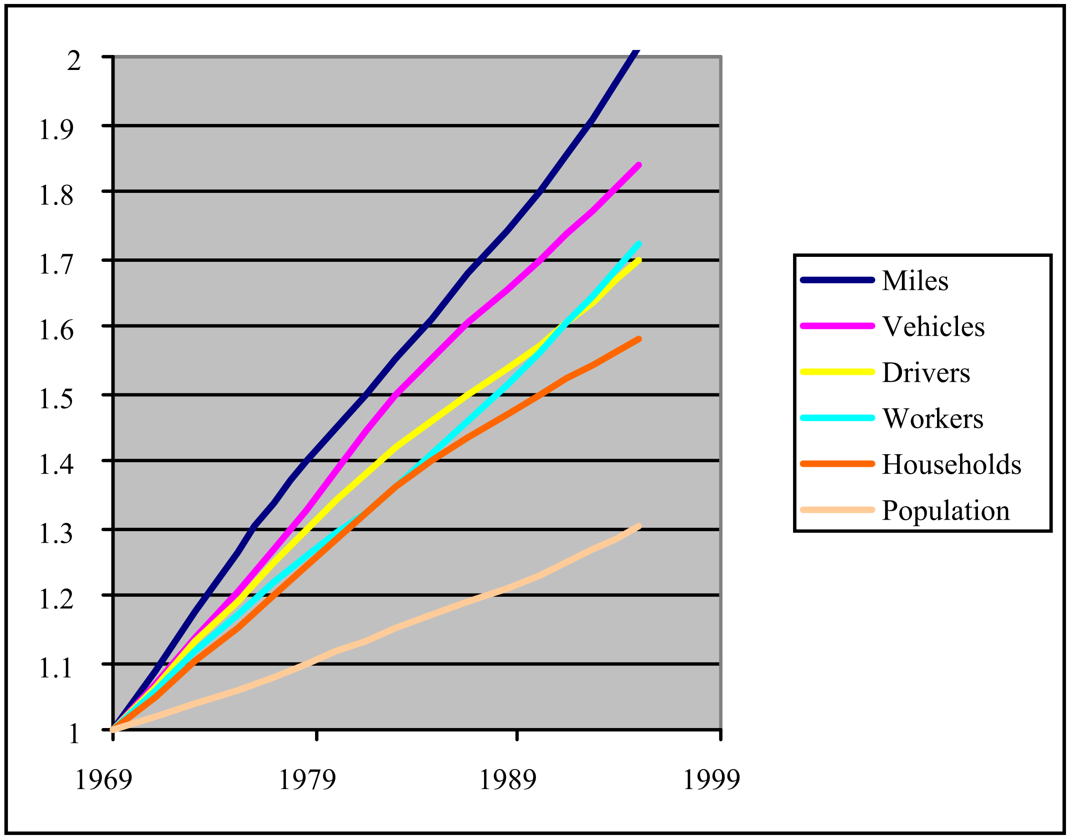


Average Income per Household
Adjusted for constant 1997 Dollars - Excluding long term stock sales
Source: Economic Policy Institute

4x speed is worth ~$68,000 /yr for top 5%

PAVE Capacity Benefit

“Personal travel demand will exceed supply in the 21st century.”



Personal Travel Trends

Normalized to 1969 values

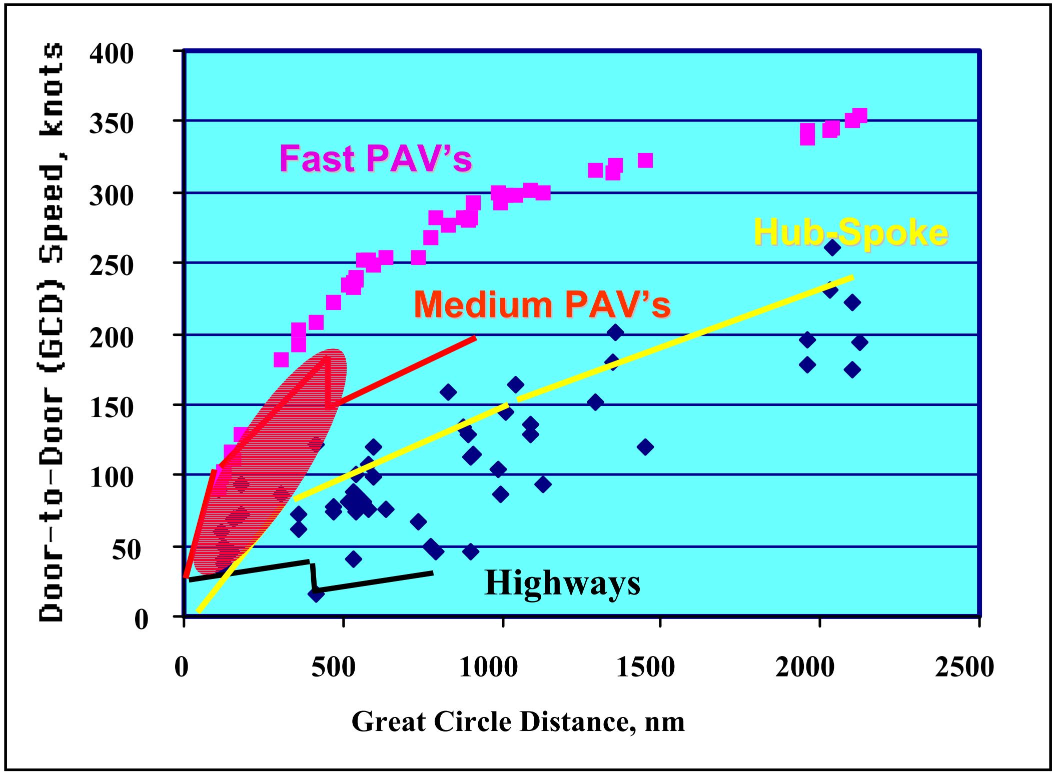
Source: Nationwide Personal Travel Survey

Average current ground speed ~ 35 mph

PAVE Mission

Improvements in lifestyle and benefits for entire U.S. population

- Top 20% and 5% income bracket breaks even with vehicles of 4x speed at a cost of $200K to $500K.
- Rental and Air-taxi have a 5-10 fold utilization increase that permits average income bracket to benefit
- Aerial services, Package delivery, Police, Rescue, EMS, Border patrol, Military, Recon, Auto-Evac...



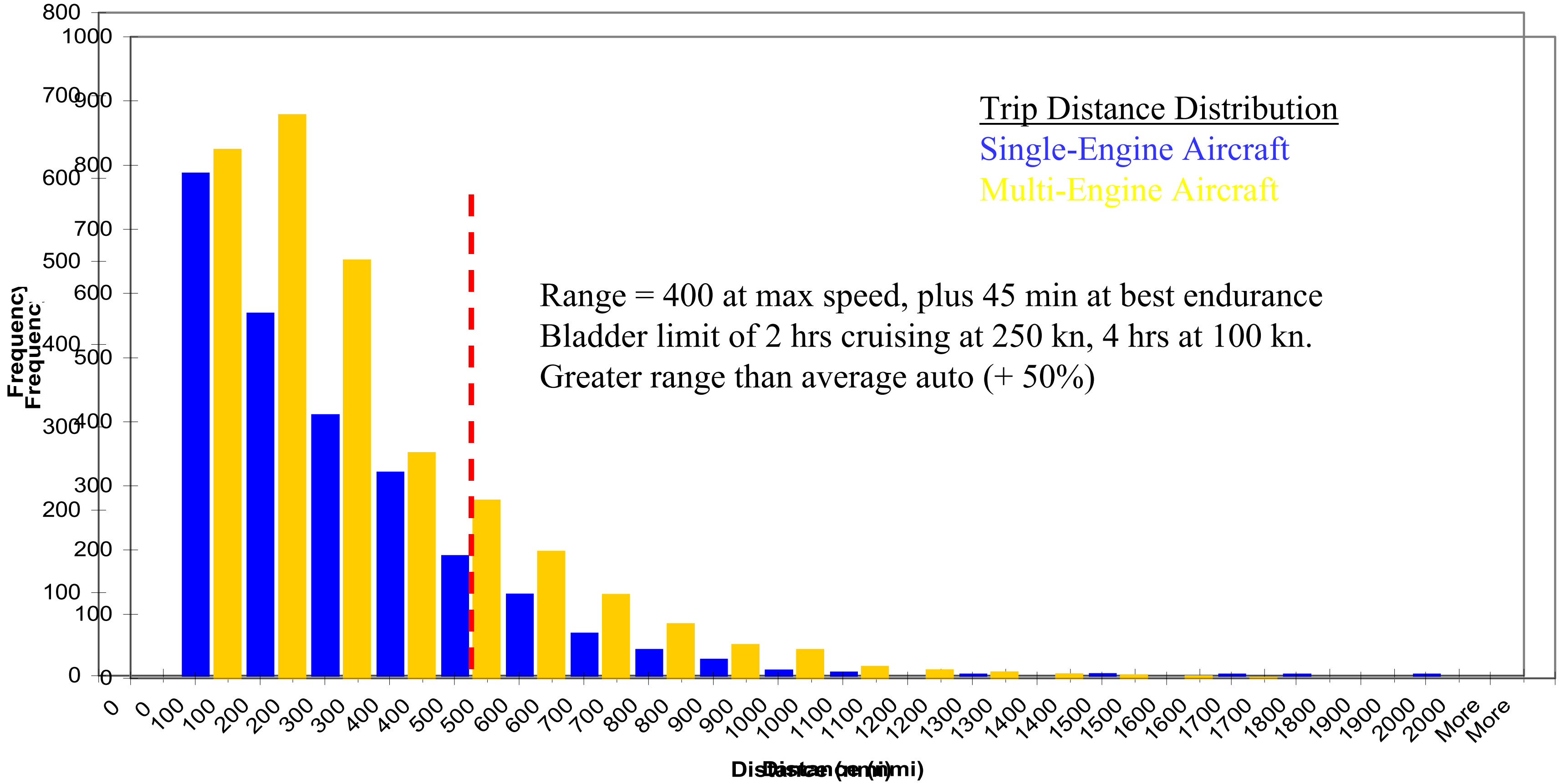
Door to Door Travel Time by Mode

Range set by average small aircraft and auto ranges

-More-

PAVE Mission

PAVE mission range captures over 90% of small aircraft departures



Prior PAVE Efforts

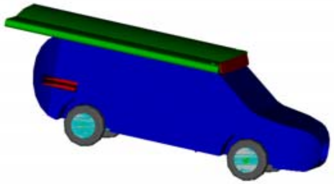
Break-apart





Fold-and-Go

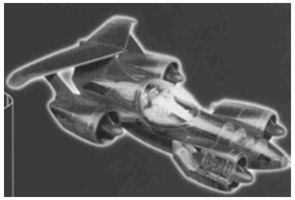
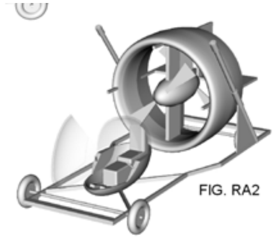




Compact



VTOL

Current PAVE Study

Design by constraint, instead of design for performance

Safety

- Simple, low complexity systems (non-professional pilots)
- Very low takeoff and landing speeds.
- Minimum external systems (hanger rash/bump/tamper proof).

Environment

- Low noise (close proximity operations)
- Automotive equivalent emissions
- Low downwash (ground erosion and FOD kickup)

Cost: Vehicles must provide a positive ROI compared to value of time.

Size: Vehicles must fit into limits imposed by existing infrastructure.

Concepts are required over a matrix of requirements

Mode Capability	CTOL 2000’	STOL 1000’	SuperSTOL 500’	V/STOL 100’
Single-Runway				
Dual-Taxi		Concept Matrix		
Dual-Side Street				
Dual-Highway				

SATS Technologies

SATS Airspace Control, Avionics, and Manufacturing

Highway in the Sky - HUD flight path

Synthetic Vision

Precision approach capability to runways

No control towers, radar, or approach lights

Internet of the air information systems

Near-all-weather operability

Self-separating & sequencing

Datalink / Databus / Database

Built-in terrain mapping and airspace avoidance

Lean Design / Lean Manufacturing

PAVE Reciprocating Engines

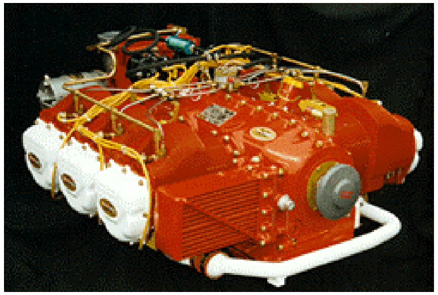
Reciprocating engines offer significant cost benefits over other engines

However the specific output (engine weight/hp) doesn't compare well

Aircraft engines

Costs are $25K to $75K (100 to 350 hp)
Specific output of approximately 2 to 2.5 lbs/hp
Most are opposed piston, air-cooled, direct drive engines
Fuel type is typically 100LL (sfc of .45 to .55)
Advanced engine: NASA GAP/TCM Turbo diesel engine

- Great sfc (~.34), Low specific output (2.3 lbs/hp)



Automotive Derivatives

Costs are $2K to $6K (100 to 350 hp)
Specific output of approximately 2.5 to 3.0 lbs/hp
Possible FAR 'like' compliance (FAA effort ongoing)
Liquid cooling permits fuel type is 86 to 93 octane (~.45 lb/hr/hp)
Advanced engine: Many exciting technologies

- EM valves, Variable CR/ER, High PR turbos

GM LS-1 Engine

PAVE Turbine Engines

Turbofan Engines

Williams/NASA GAP

10:1 thrust to weight ratio, 770 lbf, 80 lb weight
~$100K, (1000 units/year)
JP fuel

GRC is developing a model of a 2015 GAP with advanced techs

Foil bearings
Higher temperature materials / Ceramics
Higher bypass ratio (noise constrained)

The thermodynamic cycle of Eclipse's EJ22 engine is similar to the best of today's large bizjet engines while achieving a far superior thrust/weight ratio at a fraction of the size, weight, and cost.

Turboshaft Engines

Williams/NASA GAP derivative

High specific ouput, 500 hp, 120 lb weight (.25 lbs/hp)
~$125K (1000 units/year)
JP fuel

GRC is developing a model of a 2015 GAP with advanced techs

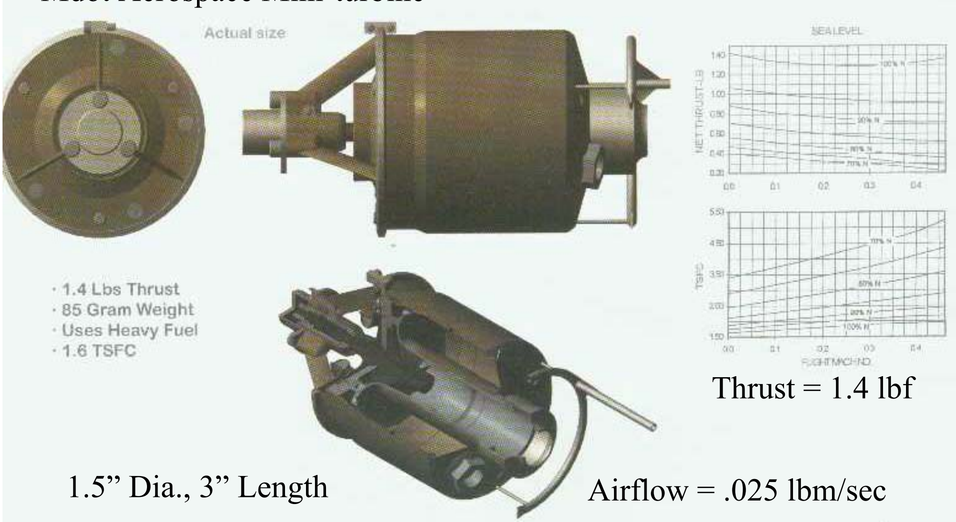
SWB Turbine

Truck turbocharger based (4.2 pressure ratio)
Fuel consumption penalty of ~30%
Specific output penalty (.75 lbs/hp)
Turbine costs are dramatically lower

PAVE Micro and Mini Turbines

Small gas turbine engines have significant hurdles to overcome

Mdot Aerospace Mini-turbine



- Achievable Overall Pressure Ratio (OPR) is reduced for small turbomachinary
- Fuel consumption is high (1.6 tsfc)
- Tolerances are more difficult to achieve
- Reynolds numbers are very low (subcritical)
- Fuel mixing time can be comparatively long
- Bearing loads at high rpm are high
- T/W ~ 6

MIT MEMS based gas turbines

Quoin Pneumatic turbines

Larger Mini’s

Mercury: T = 15.7 lb. W = 3.1 lb. D = 3.9 in. L = 8.9 in.

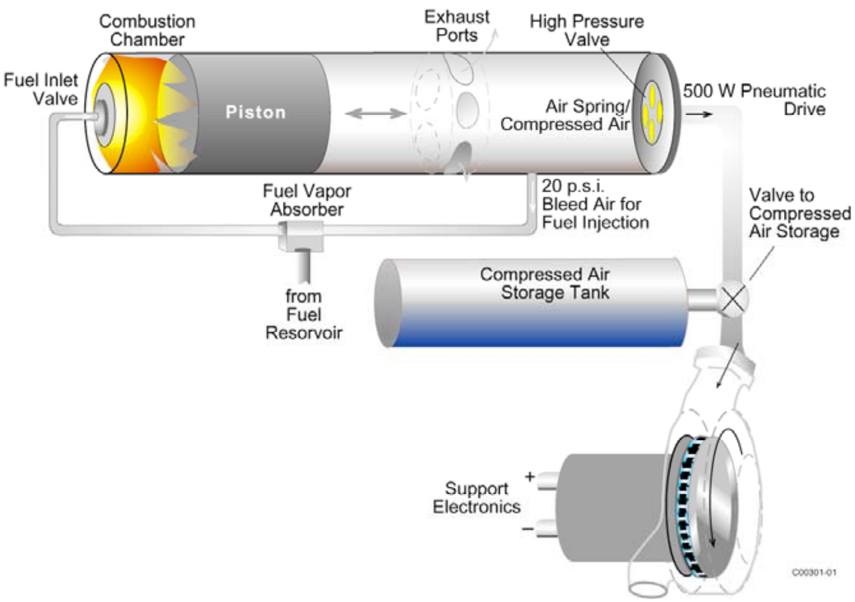
Pegasus: T = 22.5 lb. W = 5.7 lb. D = 4.7 in. L = 10.6 in.

Olympus: T = 42.5 lb. W = 6.5 lb. D = 5.1 in. L = 10.6 in.

Phoenix: T = 135 lb. W = 17.5 lb. D = 8.5 in. L = 14.0 in.

PAVE Mini Engines

Micro/Mini-Free Piston Engines: Honeywell, Sandia, Quoin, A.D. Little



- Pistons act as gas generators, no shaft work.
- Detonation Charge Compressed Ignition
- Two cycle operation with uni-flow scavenging
- Analysis yields ~40% efficiency
  (Model airplane engines ~4% efficiency)
- High piston speeds (9000 ft/min vs. 2500 ft/min)
- Lubrication free, multi-fuel
- **High compression ratio (40:1)**
- **Estimated power densities of 2 to 4 hp/lb**

Small scale limiting factors

- **Wall quenching**
- **Reduced residence time**
- **Ignition energy**
- **Friction and leakage**

Key technologies

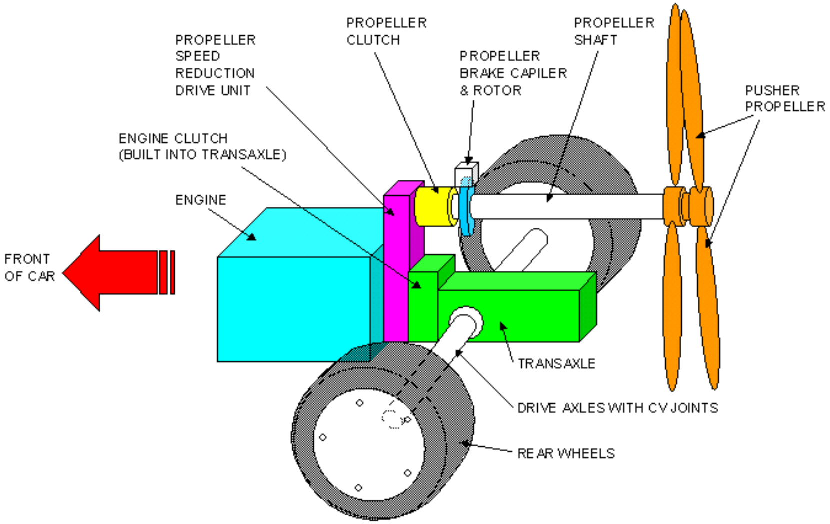
- **High speed valves and injectors**
- **Detailed combustion simulation**

QuickTime™ and a
decompressor
are needed to see this picture.

PAVE Power Drivetrain

Dual-use drivetrains provide air and ground power

Shaft driven propulsion systems (recip., turboshaft)



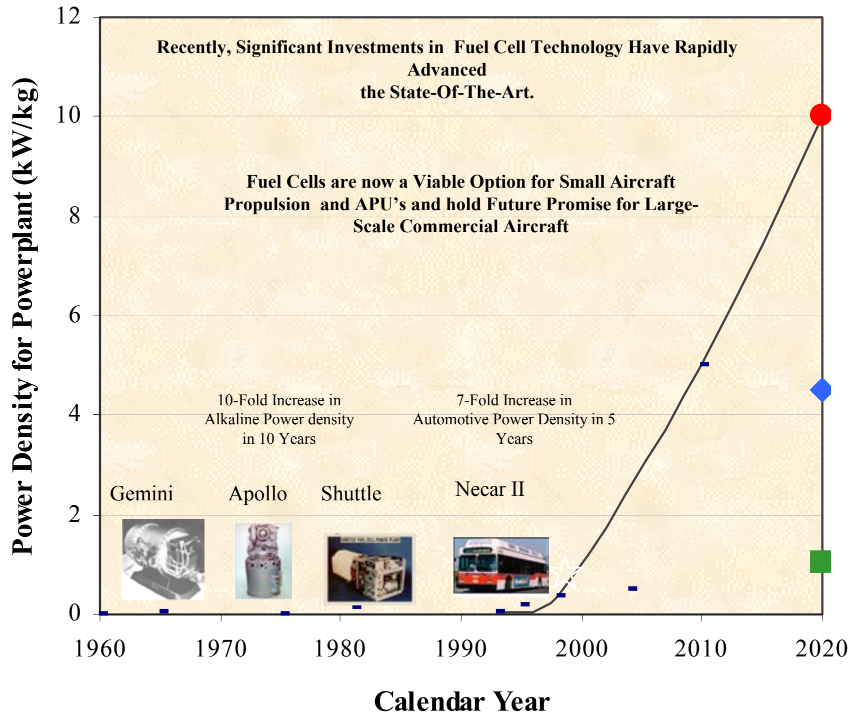
Electric hybrid concept

Gas generator propulsion systems (turbofan, free piston engine)
Exhaust gasees are diverted to a high output turbo-alternator
No batteries for storage, no AC/DC converter, all AC system
Ultra capacitors for power smoothing and peak demand
Pancake electric motors on each wheel of 15 - 25 hp

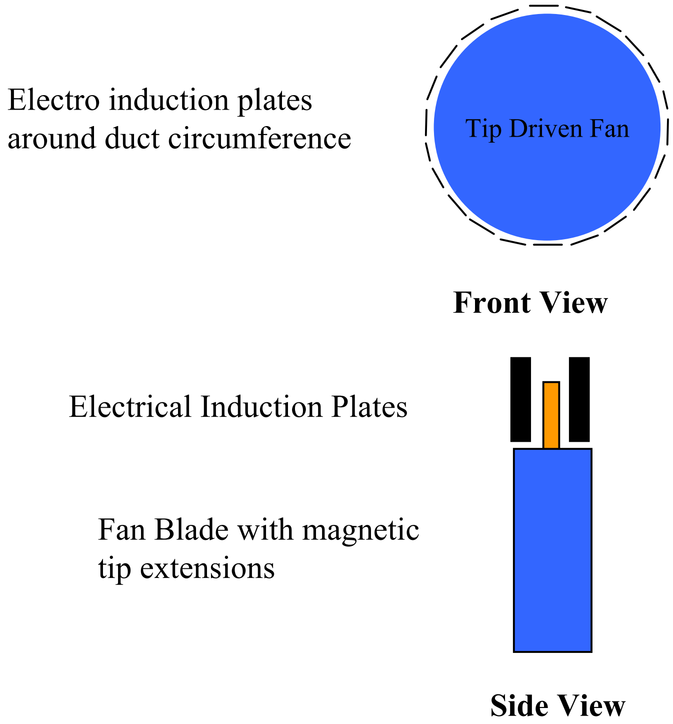
PAVE Electrical Propulsion

Electric Impulse Tip-Driven Fan (Sandia)

- Seraphim based technology (electric impulse ground rail)
- Provides redundant drive system around fan through tip impulse drive units
- Maintains isolated nacelle propulsor for aircraft integration (non-redundancy in propulsor)
- Provides potential electric propulsion solution if fuel cell technology arrives



(Recent and Predicted Fuel Cell Performance: Glenn - RAC)



PAVE Circulation Control

Circulation Control Highlift System - Coanda Jet Blowing

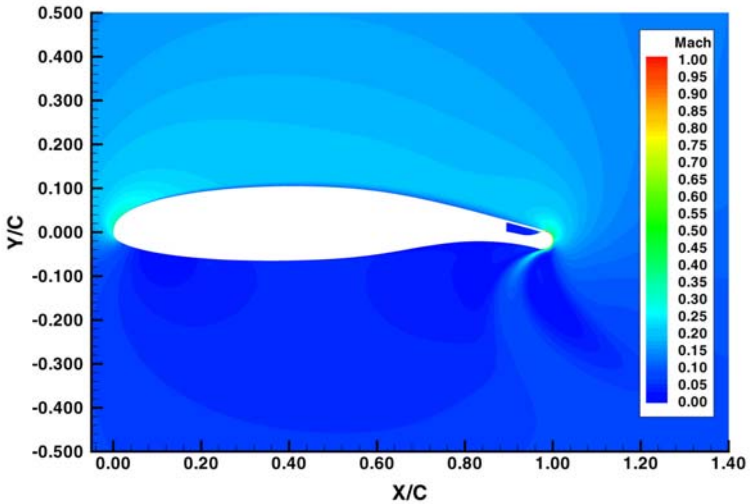
- Existing air source: can be driven off an existing reciprocating engine turbocharger
- Simple: Valves-only high-lift system is highly robust, reducing pre-flight inspection
- Reliable: No external moving parts reduces 'hanger rash' damage potential
- Highly effective: Lift augmentation is highest at lower take-off velocities
- Engine-out: Air plenum can provide several minutes of blowing
- Cruise drag penalty: Minimized with recent refinements in dual surface blowing or mini flap

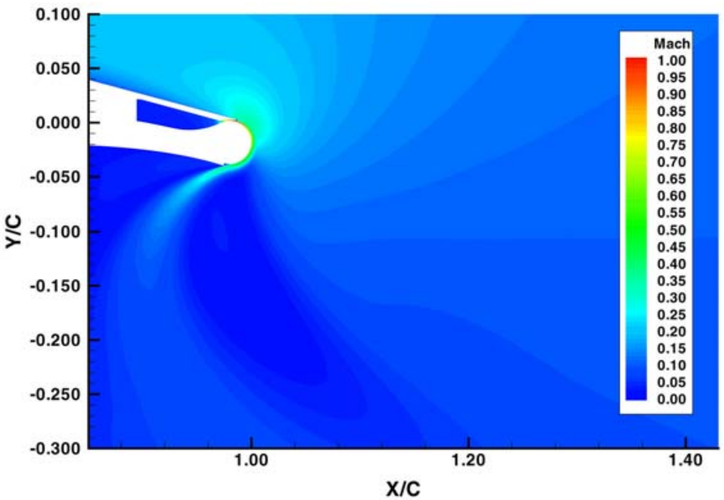
PAVE requirements are well matched to Circulation Control benefits

-More-

PAVE vehicles utilizing this technology will offer better efficiency

-More-





PAVE Circulation Control

PAVE requirements well matched to Circulation Control benefits

Blowing coef. (Cmu) is the key to the lift augmentation (for all powered lift methods)

$$C_{mu} = (\mathbf{m}_{\mathbf{dotjet}} / (2 * rho * area)) * (\mathbf{V}_{\mathbf{jet}} / \mathbf{V}_{\mathbf{freestream}}{}^{2})$$

However, there are 3 parameters that yield the same C_{mu} (or lift augmentation performance)

- $\mathbf{m}_{\mathbf{dotjet}}$ - minimize to reduce the air supply required
- $\mathbf{V}_{\mathbf{jet}}$ - limited by nozzle noise
- $\mathbf{V}_{\mathbf{freestream}}$ - determined by $V_{approach}$

A6 full-scale test demonstrated C_{Lmax} went from 2.1 to 3.9

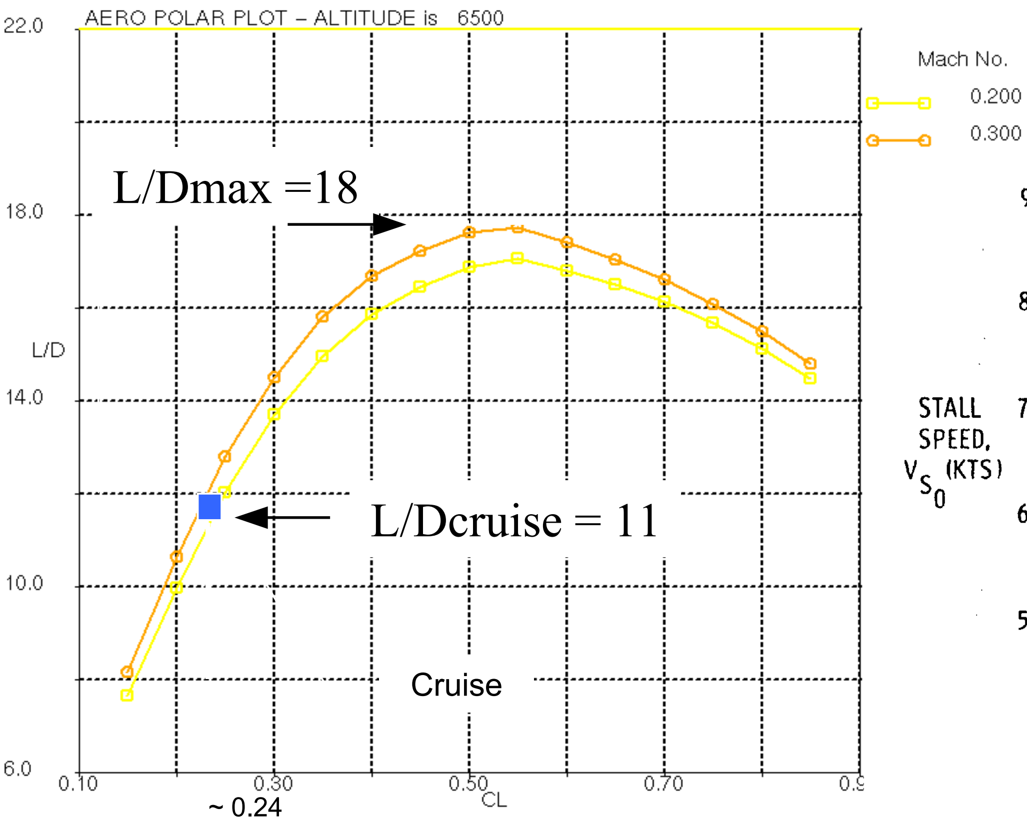
- $V_{approach}$ went from 118 to 76 knots (similar to transport wing loading)
- $V_{approach}$ for single engine General Aviation aircraft must be less than 1.3*61 knots
- $V_{approach}$ for SSTOL PAVE aircraft is ~ 30 knots to satisfy a 500’ field length
- SSTOL GA mission permits $(76/30)^2 = 6.4$ times less $\mathbf{m}_{\mathbf{dotjet}}$ or $\mathbf{V}_{\mathbf{jet}}$ for same performance

Low takeoff speeds maximize the performance of the Circulation Control system

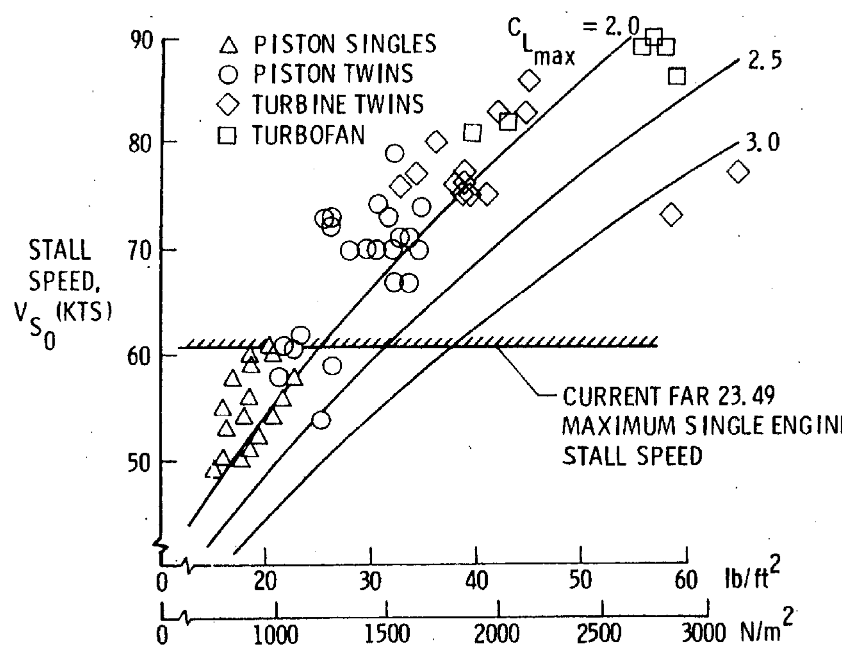
PAVE Circulation Control

Current small aircraft designs have mismatched wing area for takeoff and cruise

L/D



FAR Part 23 Limits Stall Speed to 61 knots



Circulation Control Channel Wing

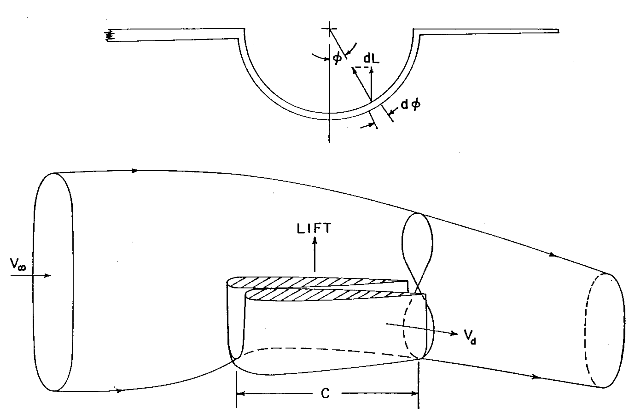
Propeller Super Circulation for STOL and SSTOL

The Channel wing achieved SSTOL performance on test vehicles, but needed to achieve high rotation angles to fully benefit.

The application of circulation control to the channel wing permits a more usable super circulation effect, with even greater $C_L$max's.

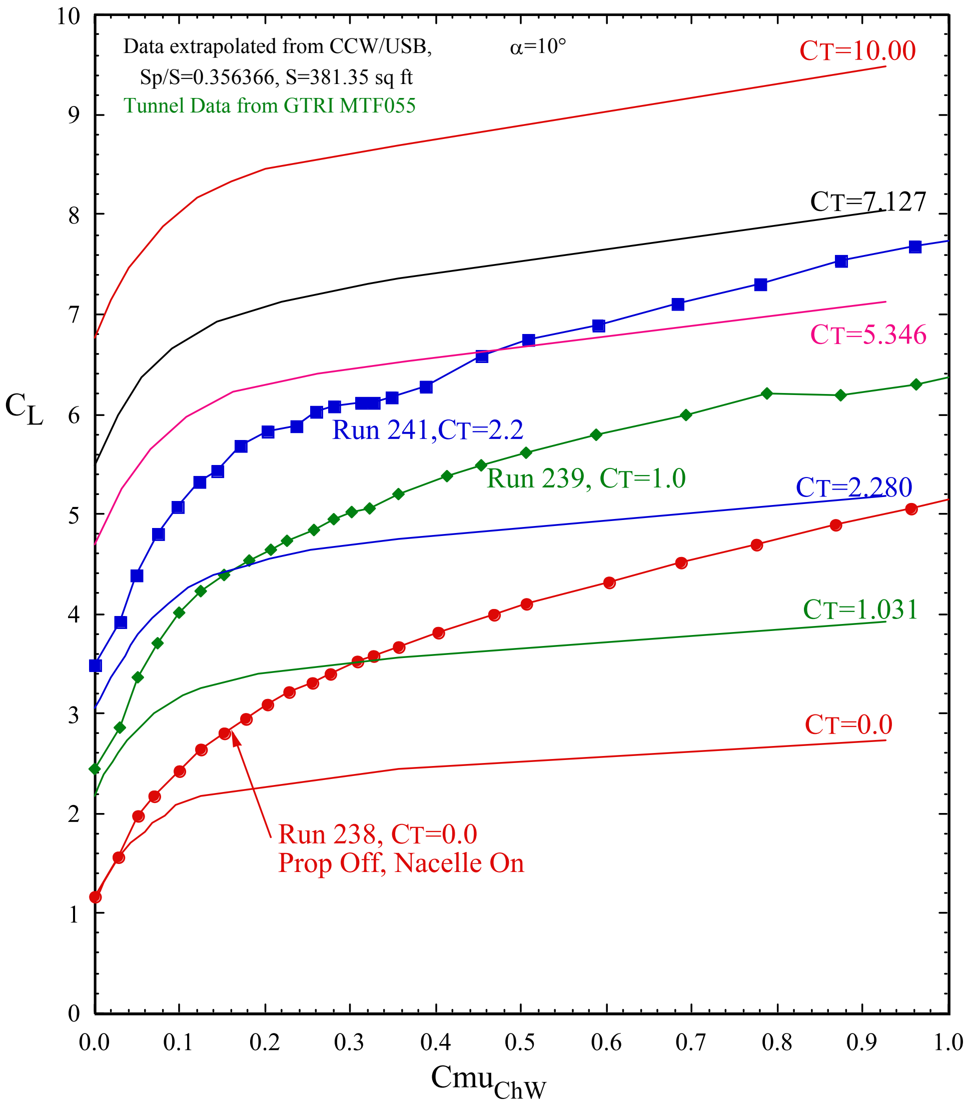
The Circulation Control Channel Wing test results indicate greater $C_L$max than any other usable method of producing lift.

-More-



Circulation Control Channel Wing

Circulation Control Channel Wing (LaRC, GTRI) Wind Tunnel Results

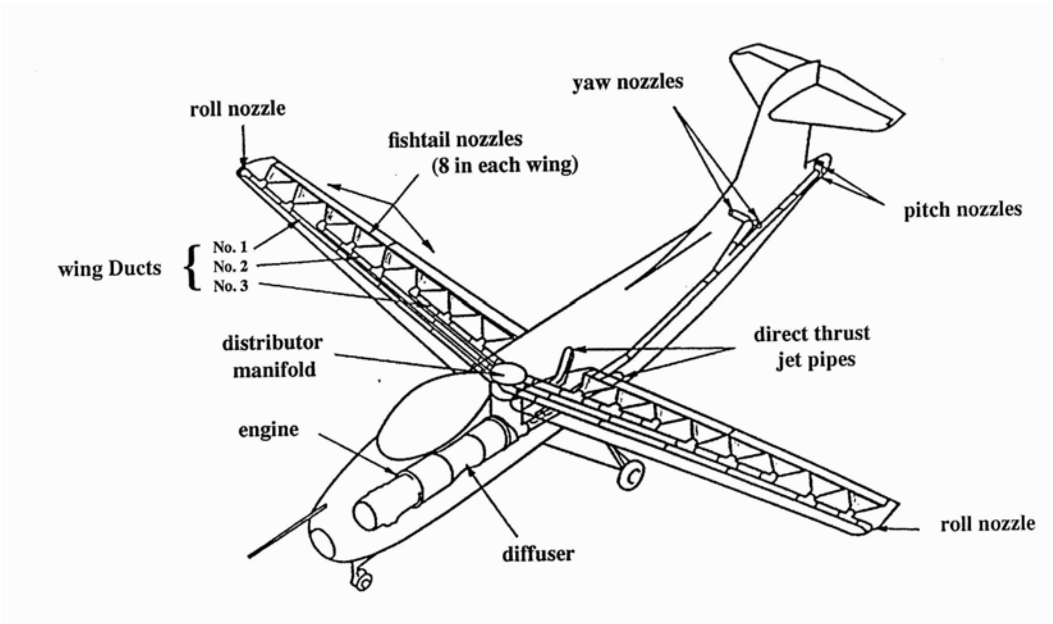


Distributed Propulsion Wing

Distributed Inlet Coupled to Wing Boundary Layer Control

SBIR just awarded to Advanced Propulsion Inc to investigate full span BL inlet ingestion

Coupling them to distributed engines will be investigated next year



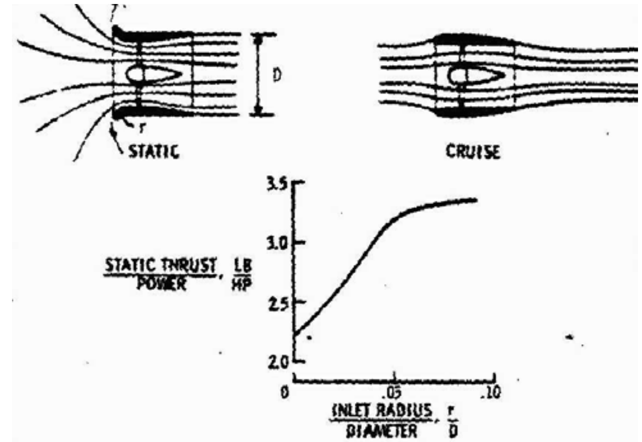
Circulation Control Nacelle

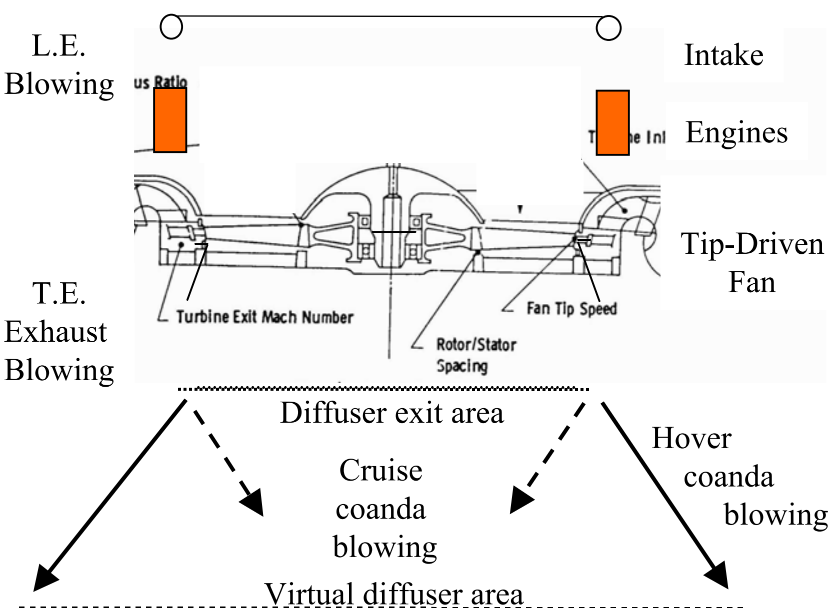
Multi-Gas Generator Fan - Circulation Control Tilt Nacelle Concept

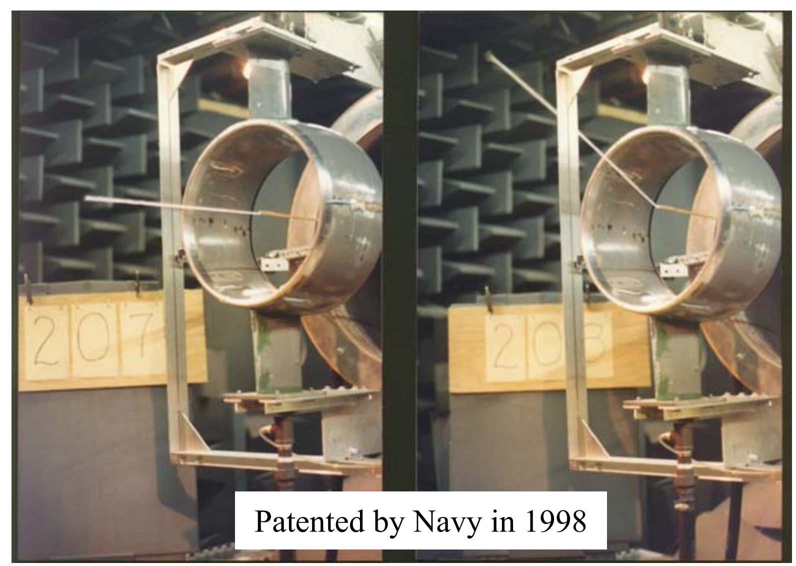
Ducted VTOL concepts suffer from the nacelle requiring two different shapes for best static and cruise performance.

Use of circulation control on duct could permit a virtual diffuser on a cruise shaped duct that actually has flow contraction.

- Increase duct lip suction at static (sizing) condition
- Increase effective exit area and nacelle mass flow
- Decrease downwash velocity on ground plane





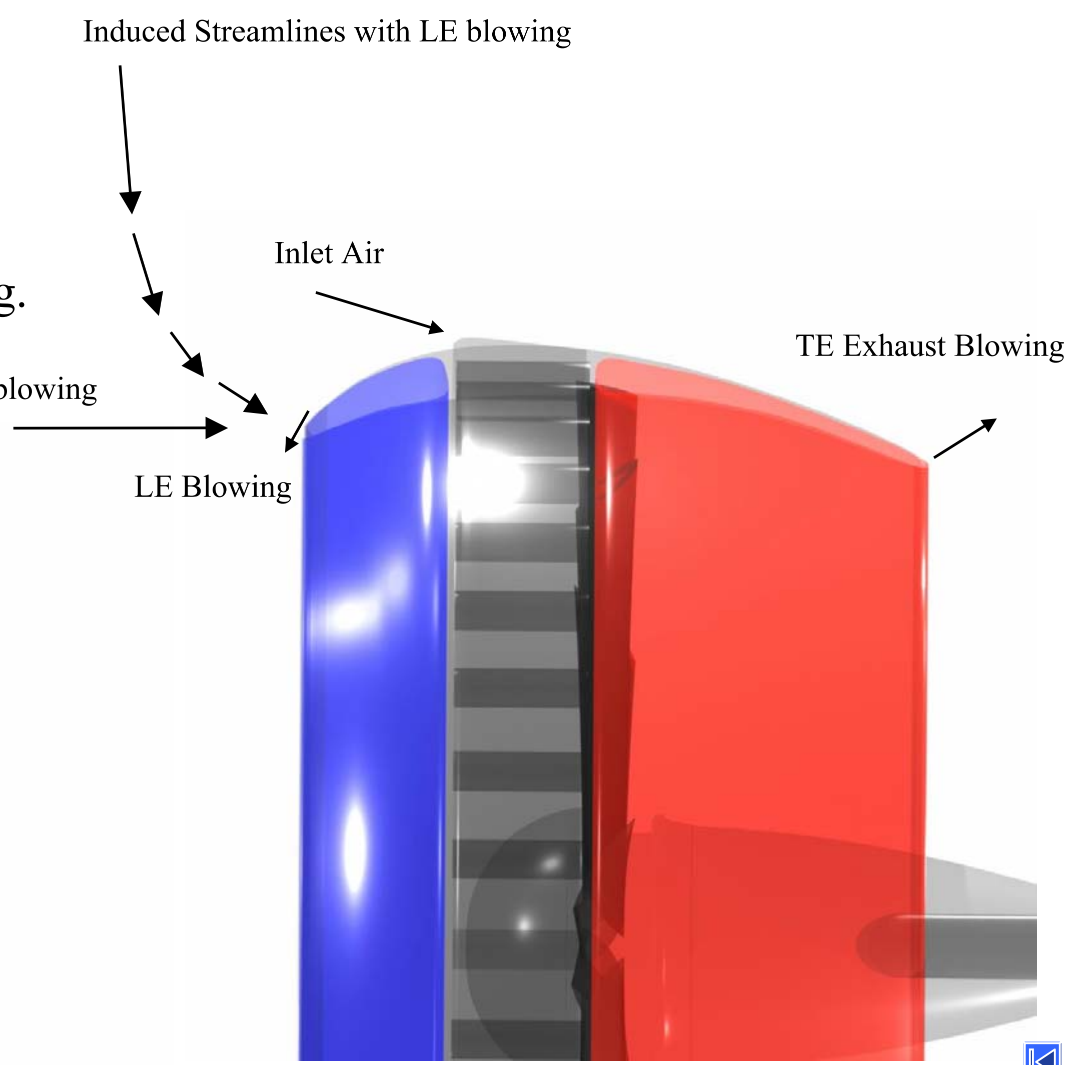


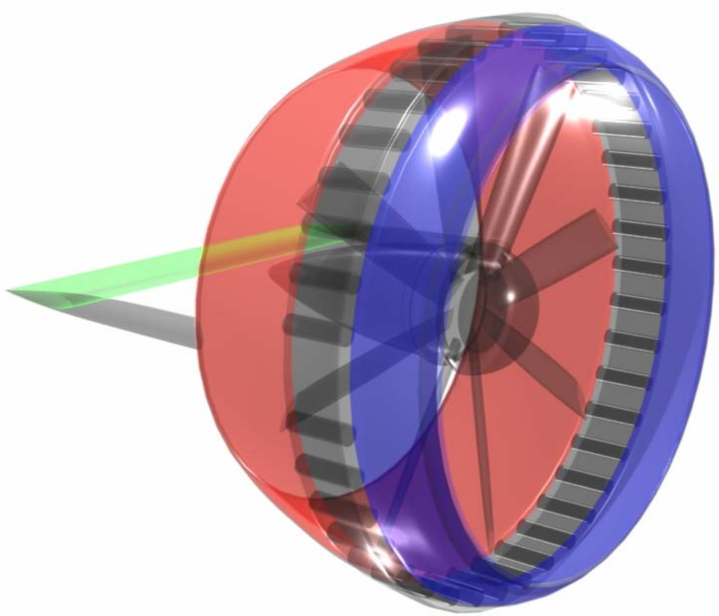
Patented by Navy in 1998

Circulation Control Nacelle

Multi-Gas Generator Fan - Circulation Control Tilt Nacelle Concept

Objective: Smallest propulsion system power requirement possible for V/STOL, Yet have well matched disc-loading for hover and cruise, and a low cruise drag nacelle that can accommodate a high turn down ratio without spillage drag.





Circulation Control Nacelle

Multi-Gas Generator Fan - Circulation Control Tilt Nacelle Concept

Benefits	Problems
Eliminates need for cross-shafting.	(Engine-out)
Provides bell mouth nacelle lip suction on cruise shaped nacelle	(T/W requirement)
Provides low cruise drag nacelle	(Cruise drag)
Reduces engine-out sizing penalty for VTOL hover	(Engine sizing penalty)
Provides downwash velocity reduction through increased diffusion.	(Ground erosion/debris)
Provides nacelle separation control in transition and crosswinds	(Transition separation)

Plus, fuel is only being routed to nacelle, not all over…as in a 'pure' distributed concept.

While the gas generators are highly redundant, the fan isn't redundant at all.

ASRS database analysis showed only 4% of all propulsion system reported problems were related to the fan, while 71% were due to the gas generators.

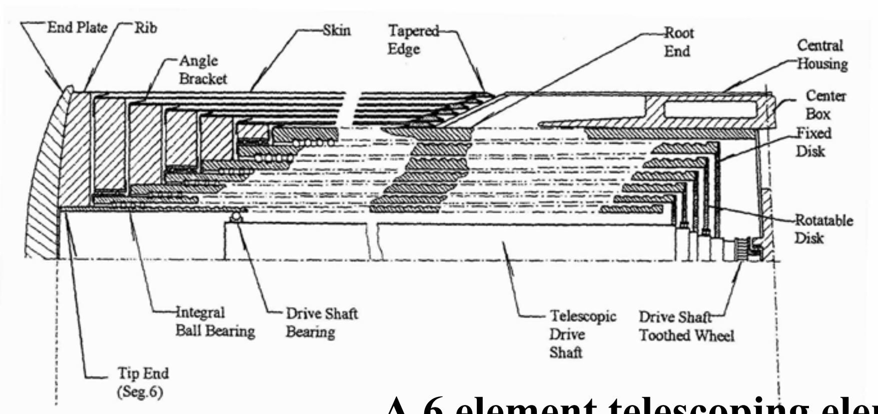
Span Constrained Structures

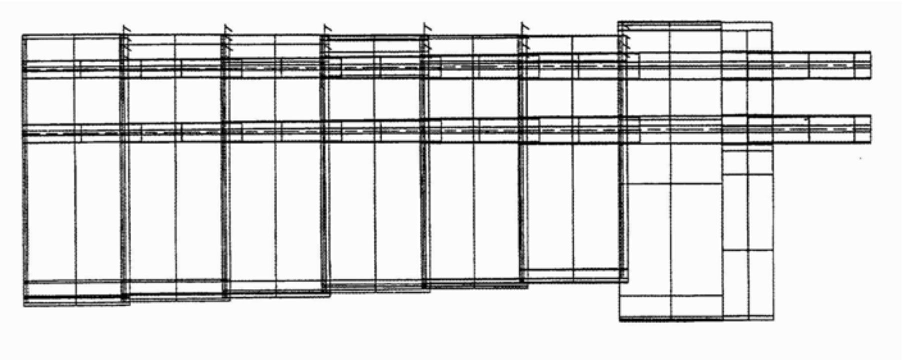
Structures - Severe Span Constrained Concepts

Telescoping wings
- AFA/VPI multi-element collapsing spar

Folding wings
- Navy wing fold technology

Inflatable air-beam wings
- High pressure (500 psi) air beam spars
- Expandable foam between air beams
- Currently tested in ballistic UAV's



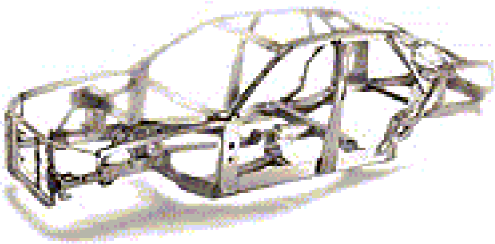


A 6 element telescoping element from AFA/VPI concepts

Ultra Lightweight Structures

Aluminum Structures

Audi A2 all aluminum
340 lb body frame and shell
43% reduction in frame and shell weight
Body cost increased 1.86 times ($930 to $1,727)
1973 lbs vehicle empty weight



Composite Structures

GM Car built by Scaled Composites
420 lb complete body weight

Hybrid Structures

Dodge ESX - aluminum structure, thermoplastic panels

Expecting weight reduction to make up all the difference isn't the solution, body weight helps stability on ground.

LaRC Dual-mode CTOL Concept

Sizing Requirements and Issues

Geometry
Folded 7’ x 7.5’ x 20’ bounding box (H x W x L)
Garage storage and cross-wind highway/width comfort limited
Auto-like entry (no wing interference)
Rear wheel location determined by C.G. and takeoff/landing rotation
Engine-out climb and cruise drag require minimum of 26’ span

Payload
4 passeners @ 200 lbs (including baggage)
Minimal C.G. excursion - no active C.G. control
Baggage volume 10 ft3 (average 4 pass car is 15.7 ft3)

Powerplant
65 mph highway cruise ground power sizing
No acceleration requirement

Wing
61 knot stall speed (2000 ft field length)

FAR Part 23 and FMVSS Part 571+ Compliance
NHTSA Highway capable design
Bumpers, lights, seats, restraints, airbags,
Breaking, rollover, crash protection

2002 Mercedes Vaneo

1992 Chrysler Cirrus Concept

LaRC Dual-mode CTOL Concept

Characteristics

Canard, rear wing design
- Height is a limiting factor
- Storage of wing beneath payload cabin adds over 1’ to height

Stowage of wings with 25’ span(28’ effective)
- Single element inner telescoping panel (utilizing body depth for non-telescoping hinged spar)
- Outer double fold (inner fold 150 degrees, outer fold 60 degrees)
- Single element telescoping canard (utilizing body depth for non-telescoping hinged spar)

Dual turbofan propulsion system
- Rear body, side inlet integration
- Current GAP turbofan is not well matched to mission
- Turbo-alternator ground power generation from single turbofan near idle
- Integral wheel electric motors

Current assumed weight is ~3200 lbs with all aluminum

Large front and aft volume house telescoping structure and rotating wheel fairings

Design speed of 250 knots

VPI Dual-mode CTOL Concept

Geometry Selection Criteria

Conventional wing and tail design

6 element telescoping wing (on each side)

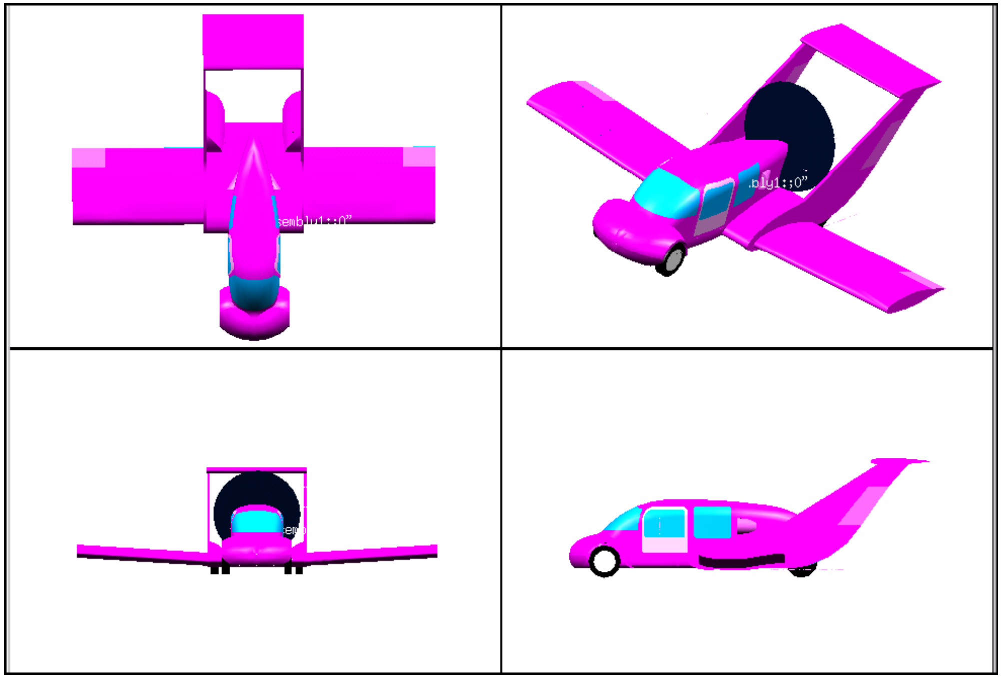
25' length currently violates bounding box limits (must be garage capable)

Pusher propeller / reciprocating propulsion system

Transaxle coupling of reciprocating engine for ground and air propulsion

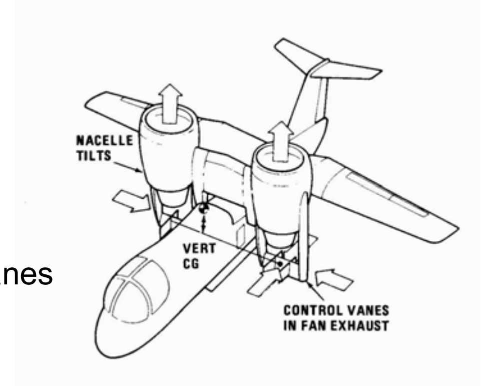
Gross weight of 3300 lb before normalized

Design speed of 150 knots



LaRC Single-mode VTOL Concept

Multi-Gas Generator Fan - Circulation Control Tilt Nacelle Concept



2 person payload
10’ W x 7’ H x 20’ L folded - Foldable outer wing panels

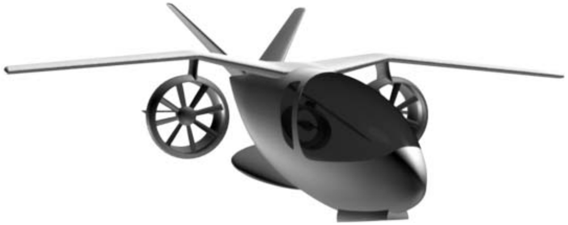
Minimize powered lift complexity and uncertainty
- Based on Grumman 698 design with established database
- All control forces generated through engine control vanes
- Engine rotation brake system - No mechanical rotation, uses thrust deflection vanes
- No Reaction Control System required

Slight forward sweep outer panels for center of lift co-location with C.G. in hover

Multiple small gas generators powered tip turbine fans
- Minimizes engine-out sizing condition

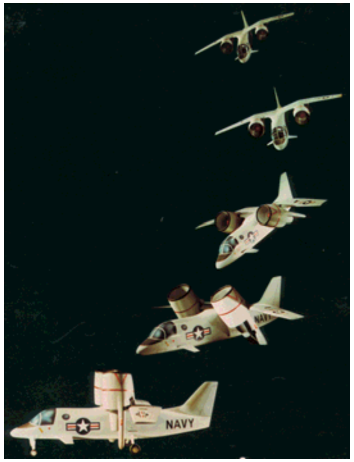
Circulation control nacelle virtual diffuser
- Static and cruise optimized duct shape
- Limits nacelle diameter

Approximately 2000 lbs gross weight



LaRC Dual-mode VTOL Concept

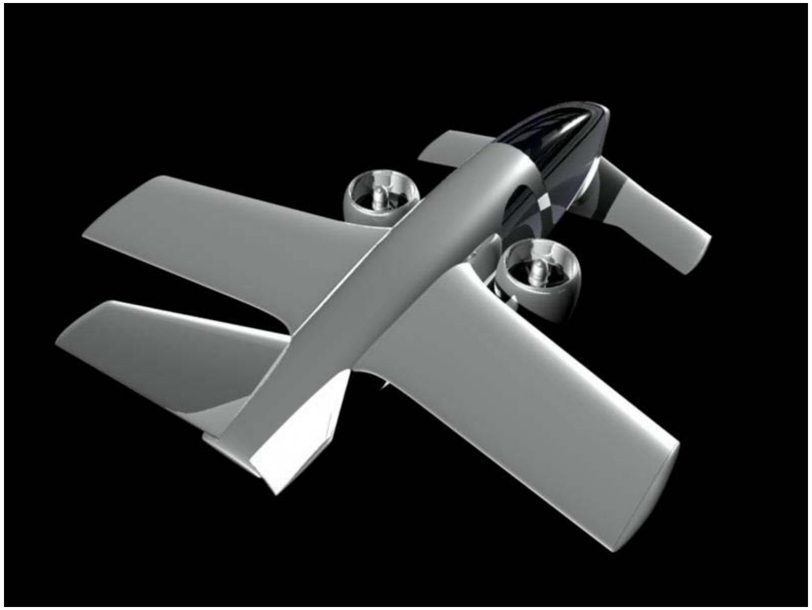
VTOL: Tilt Nacelle



Same as LaRC Tilt Nacelle VTOL except

FMVSS Part 500 compliance (25 mph speed limit)
7.5’ W x 7’ H x 20’ L folded - Foldable outer wing panels

Canard and wing planform for co-location of center of lift and hover C.G.
Body mounted nacelles of higher discloading to comply with 7.5’ width
Folding wing (folds back and down)
Half span telescoping canard



LaRC Dual-mode SSTOL Concept

Side-Street Dual-mode, SSTOL: Single Spiral Wing

Limited to 2 person payload due to severe span constraint
FMVSS Part 500 compliance (25 mph speed limit)
7.5' W x 7'H folded - Foldable outer wing panels (down)
Minimum discloading possible within auto bounding box

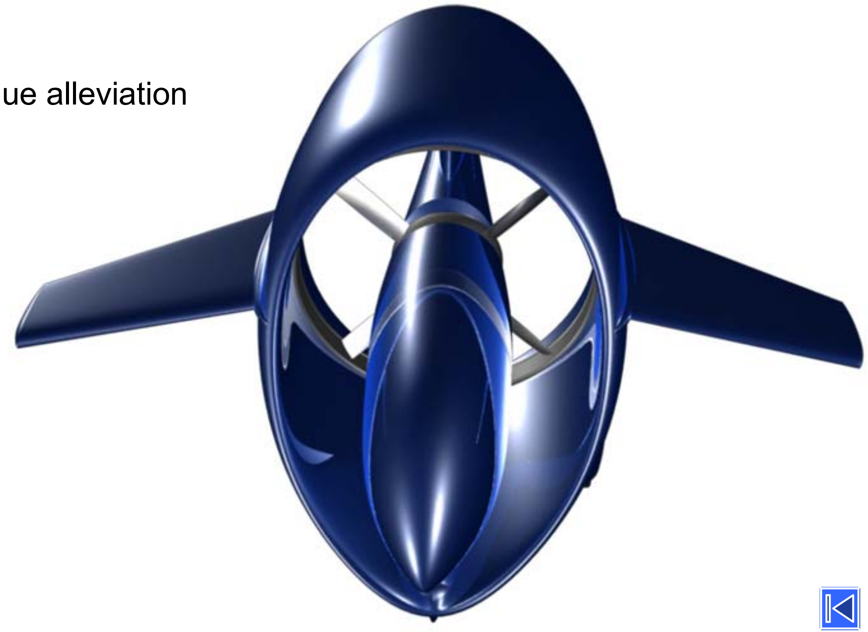
Combination concept of Channel wing with Aerodyne

- Channel permits forward loading of lifting surface to balance rear thrust deflection
- Rear duct permits full rotation propeller sealing - decreasing propeller load variations
- Non planar lifting surface permits improvement in span efficiency, with minimal footprint
- Continuous loading across channel - effectively close coupled tail
- Very high effective span potential at cruise Cl's (e ~ 5.0), but at price of high wetted area

-More-

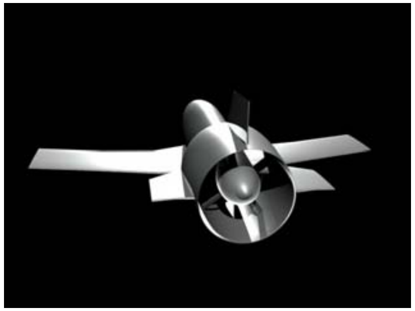
Dual reciprocating engines turning counter-rotating propellers for torque alleviation

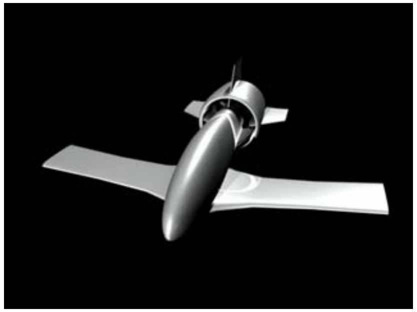
- No cross-shafting
- Lightly loaded propellers - low discloading

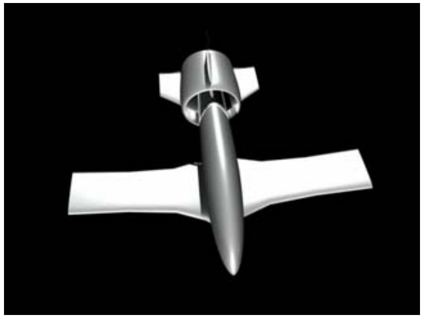


Single-mode Concepts

Single Mode CTOL, STOL, SSTOL: Tailfan







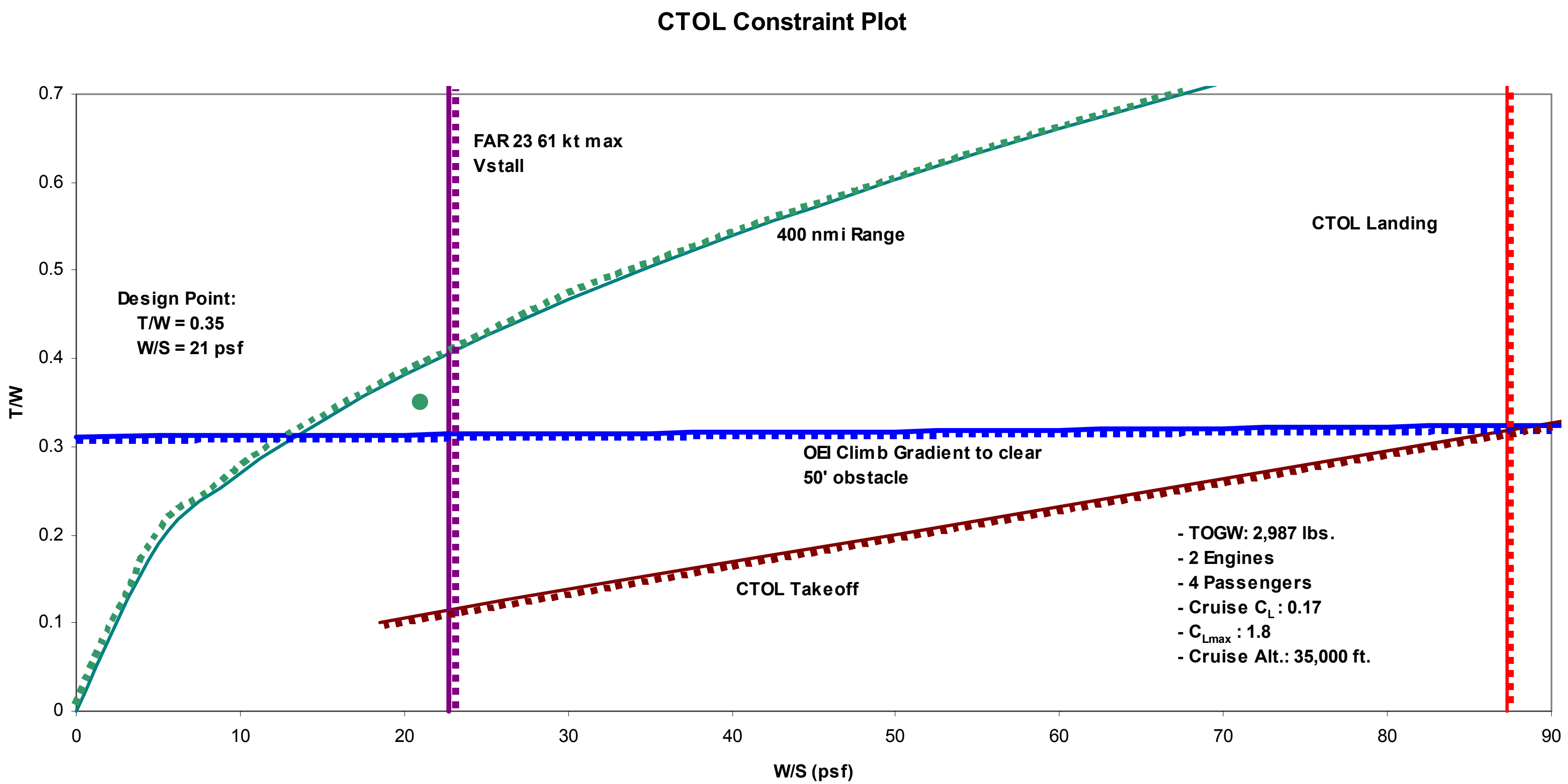
Model T of the air
Rental car to complete doorstep operation

Low cost design approach - meet a minimum buy/operate cost to offset no ground capability
- Automotive derivative engine with turbocharger (for altitude compensation only)
- Direct drive tailfan @ 3500 rpm (lower engine specific output, no gear reduction)
- Design for manufacturing approach instead of design for performance
- Minimize number of panel molds - symmetric tail, duct, and some wing sections
- Aero performance penalty for simplified skin stiffened structure

Low noise design approach - meet the noise constraint with minimum penalty
- Hamilton Standard Qfan derivative fan
- Low tip speed on fan (decreased performance)
- Low discloading
- Multi-bladed higher frequency noise
- Acoustic duct shielding
- Uniform inflow
- Large muffler volume in tailcone

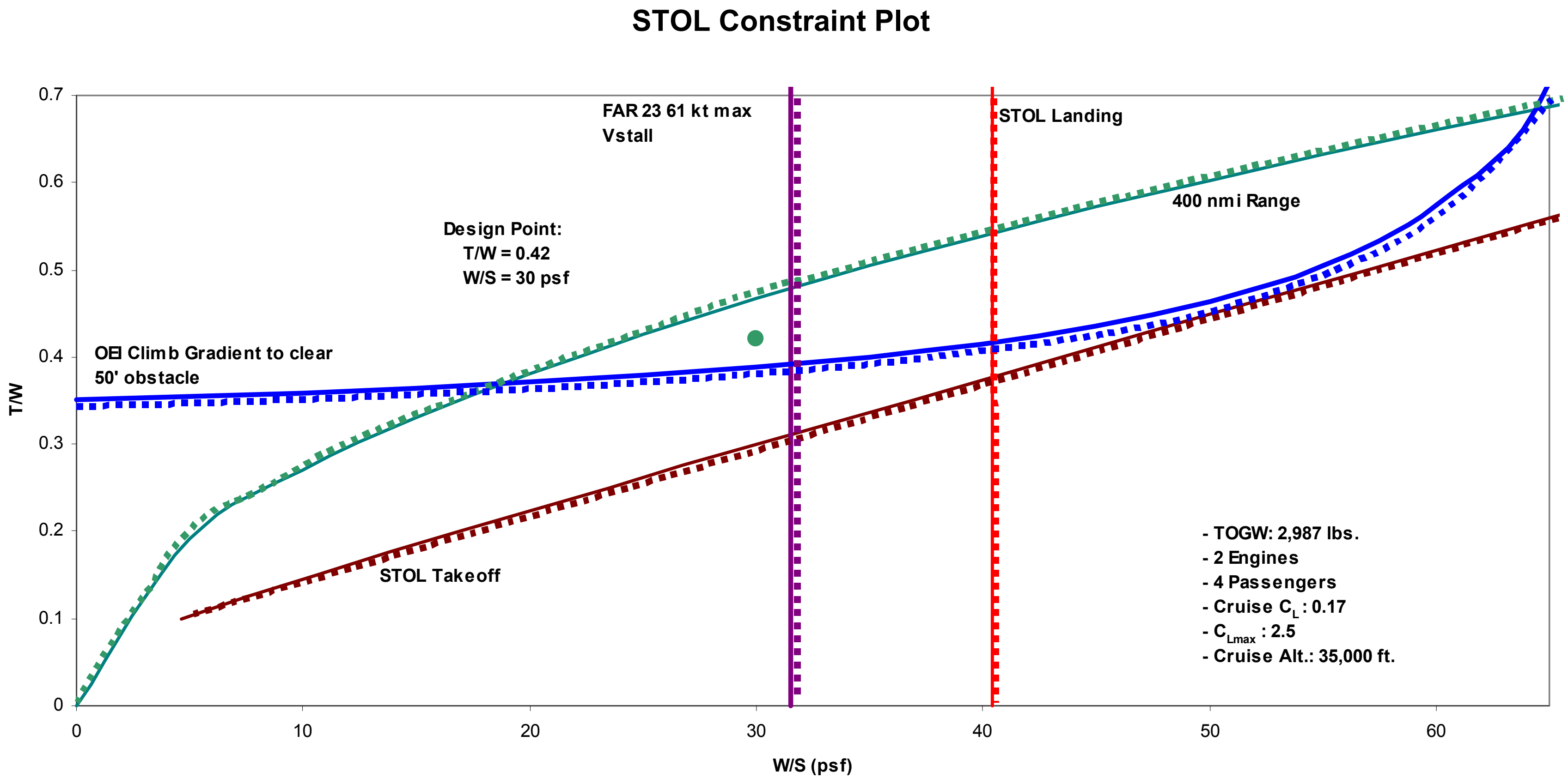
STOL version: Full span flaps and leading edge slot
SSTOL version: Turbocharger powered circulation control highlift system for

Study Results



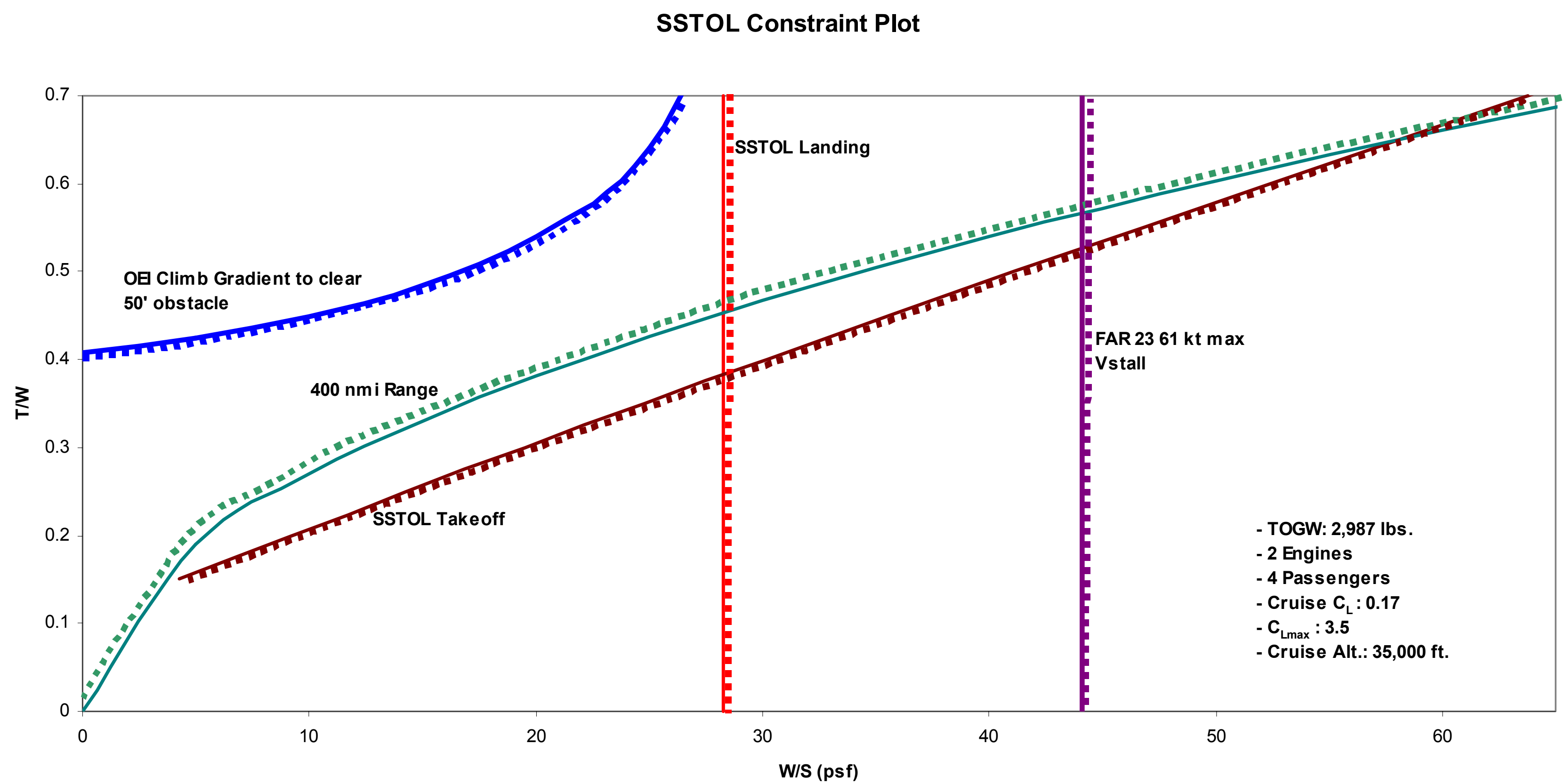
The CTOL requirements are easily met by a conventional configuration. Note that the range constraint will move as cruise conditions are adjusted.

Study Results



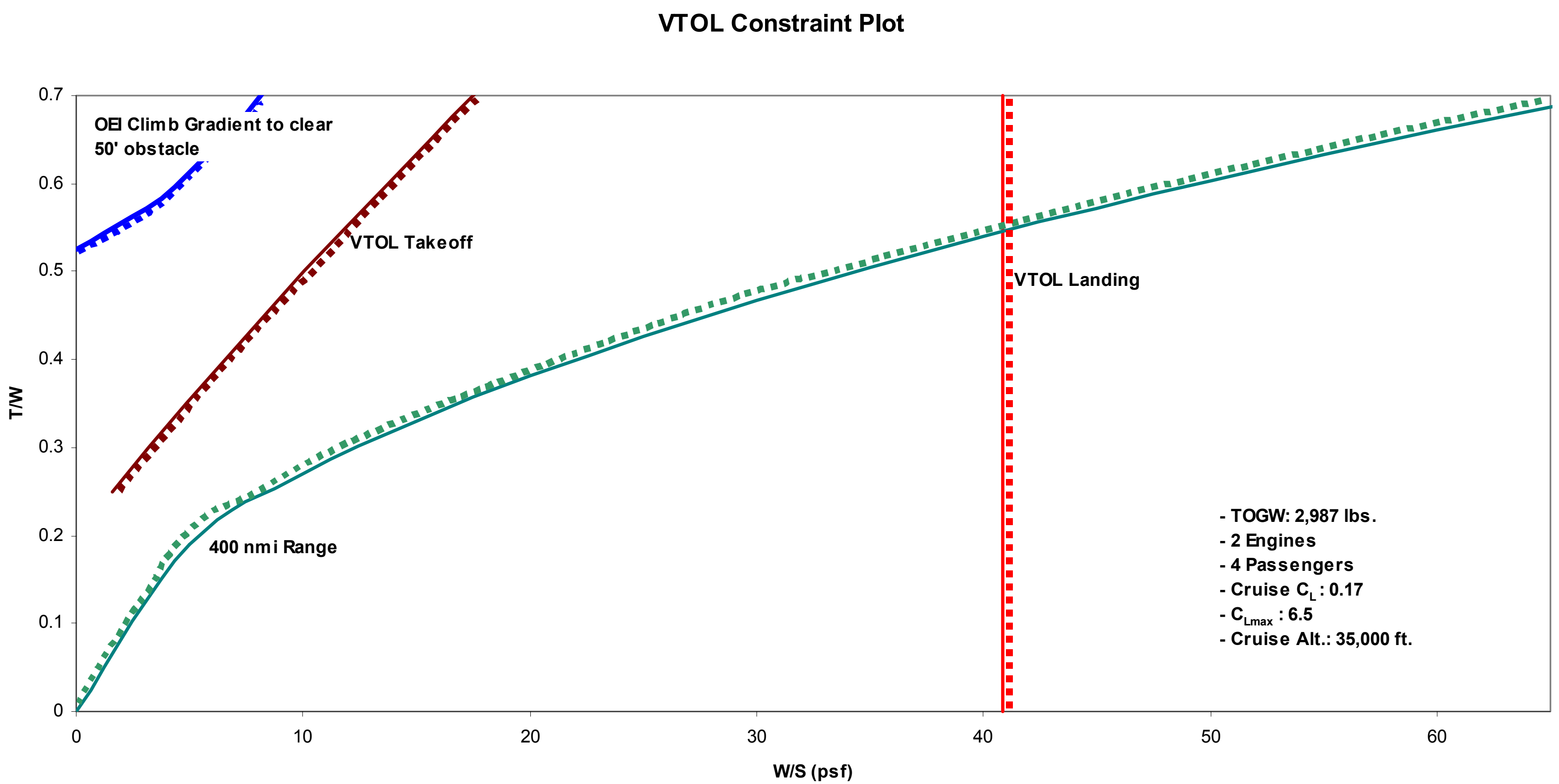
Here a higher C_{Lmax} was assumed; this is reflected in the higher FAR 23 allowable wingloading. Again, the range constraint can be manipulated by adjusting cruise conditions to expand the design space if necessary.

Study Results



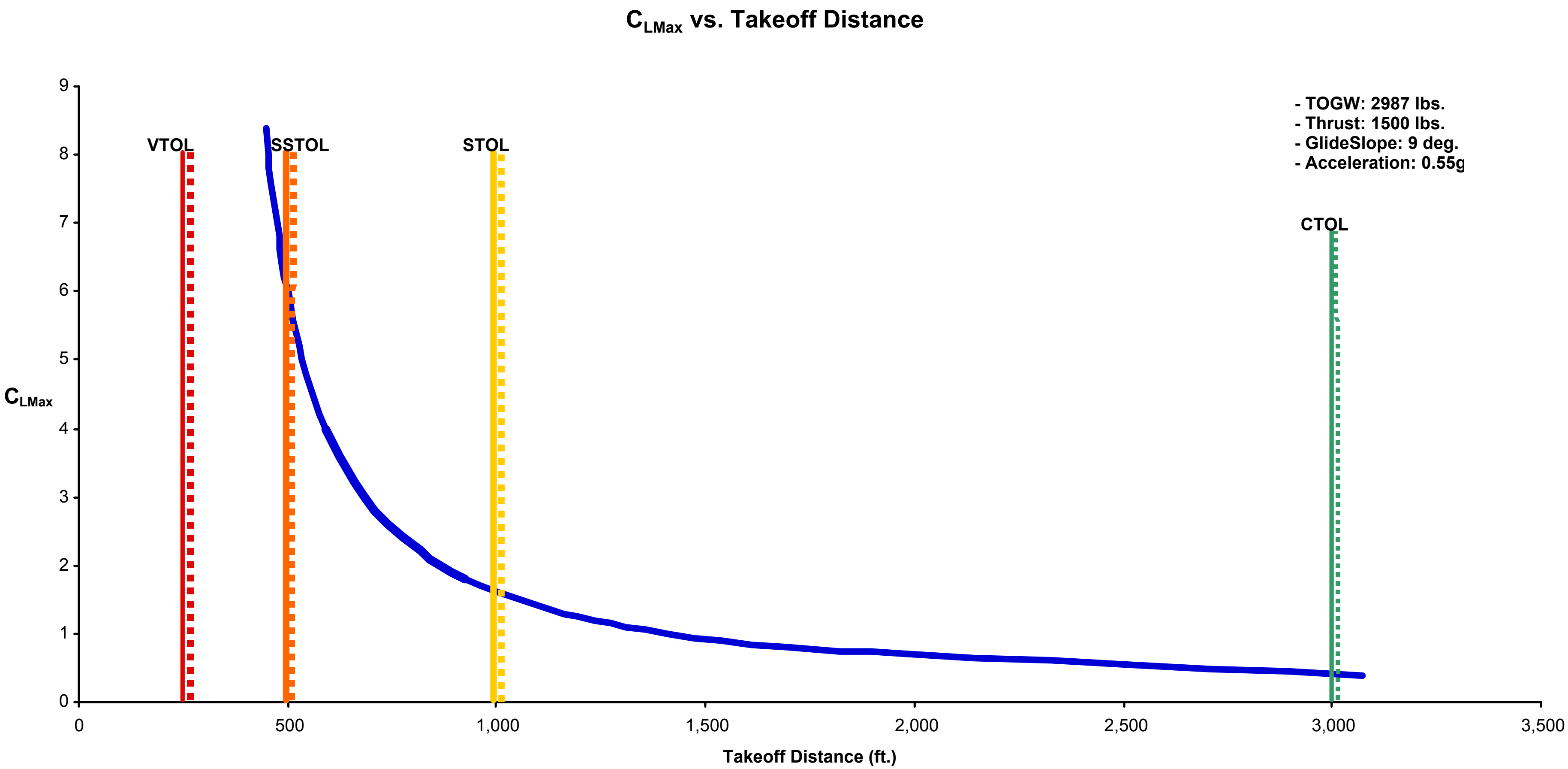
Here the range constraint will need to be adjusted to create a viable design space. A highly specialized conventional configuration could fulfill the SSTOL mission.

Study Results

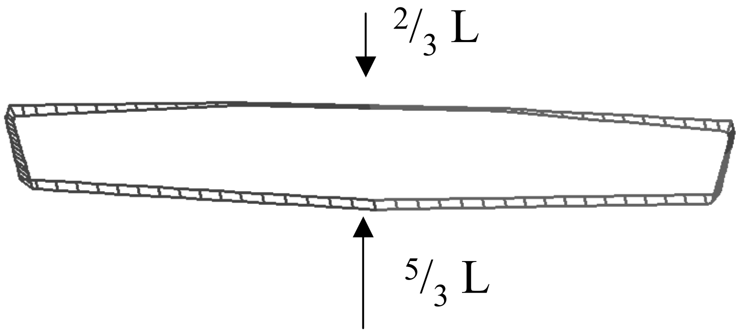


It is doubtful that a conventional configuration will meet the VTOL requirements even with the assumed C_{Lmax} of 6.5.

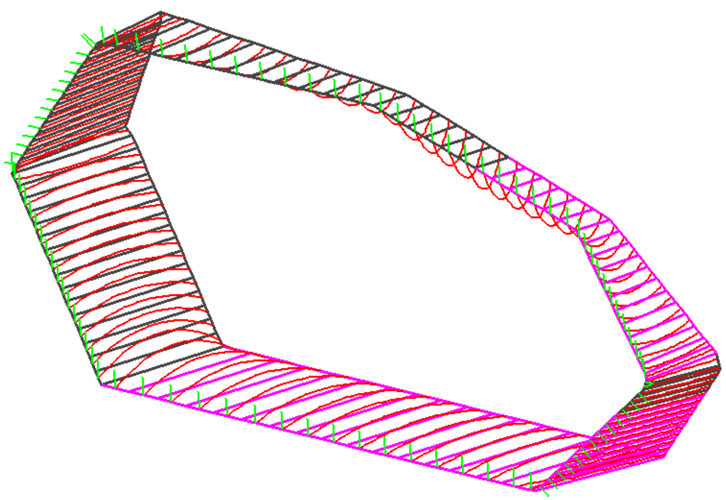
Study Results

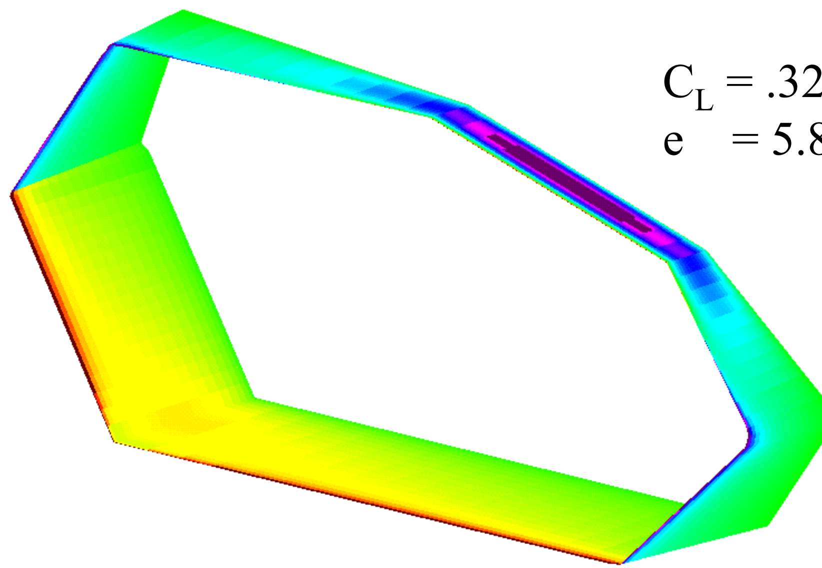


Non Planar Constrained Span



A no tip vortex system model offering high effective spans at cruise at the price of high wetted areas





$C_L = .325$
$e = 5.81$